Appendix D

Scour Hydraulic Analysis

Purpose

These calculations assess the potential scour in the South Fork of the Skykomish River during construction of the levee remediation. The summer construction window, due to fish closure on the river, is from 1 July to 15 September of any year.

Given

Based on the topographic and hydrographic surveys of the river done by Bush, Roed & Hitchings (BRH) in May 2005, the river bed in front of the levee has an average slope of 0.0028 (0.16º) between the bridge and the west end of the levee.

Assumptions

Using data from the FEMA (2001) Flood Insurance Study and the survey data for the river, the flow characteristics of the river during construction and during flood events are assumed to be as given in Table 1.

Table 1. Skykomish River Flow Characteristics about 300 Feet Downstream of the 5th Street Bridge.

Flood Frequency	Elevation, ft NAVD88	Discharge cfs	Average Flow Area ft^2	Average Velocity ft/sec
Summer Low	917.2	6,000	325 249*	18.5 24.1*
Summer High	921.2	12,000	1,147 743*	10.5 16.2*
1-yr	924.2	20,500	1,804	11.4
2-yr	925.0	24,000	1,984	12.1
5-yr	926.0	30,000	2,211	13.6
10-yr	926.8	32,200	2,396	13.4
50-yr	928.6	47,400	2,818	16.8
100-yr	929.4	54,300	3,009	18.0

* With cofferdam installed on river bar.

The elevations and discharges as a function of recurrence intervals are from the calculations of river flow (RETEC, 1 February 2005). The cross-sectional areas are from a section cut across the river 300 feet downstream of the bridge and based on the BRH May 2005 survey data.

The river bed is composed of sand, gravel, and cobbles. Based on a visual inspection of the river bed, the estimated median grain size (D_{50}) is 2 inches (50 mm, 0.17 feet).

Assume a grain size distribution as presented in Table 2. While boulders can be found in the river, it is assumed they are not present on the surface of the river bed or, if so, are too big to move.

Table 2. Skykomish River Sediment Distribution.

Grain Size Description	**Median Grain Size mm**	**Size Distribution %**
Sand	0.074 – 2.0	10
Gravel	2.0 - 76	60
Cobbles	76 - 300	30
Boulders	300+	0

Calculations

Localized scour may occur in the river bed due to flood flows or concentrated flows, like that between the cofferdam and north bank during construction.

The ASCE (2005) methods, which are derived from the work of Lagasse et (2001), are used to assess scour potential. First, the critical conditions (incipient motion) are calculated. Under critical conditions, the hydrodynamic forces on a grain are just balanced by the resisting forces. Sediment grains smaller than the critical sediment size will be transported downstream and grains equal to or larger will remain in place.

The critical conditions are assessed using a calculation spreadsheet (Attachment A) based on the ASCE methods. The calculation results need to be assessed with caution. The methods upon which the calculations are based are empirical approximations. The results are order of magnitude only, but they can be used in a qualitative sense.

The river cross-sectional areas reported in Table 1 are much less than those used in the flood study. For example, the cross-sectional area for section AT (about 300 feet downstream of the bridge) is 4,576 ft^2 at the 100-year flood elevation as measured by photogrammetric means in 1993. At the same 100-year flood elevation, the CADD measured cross-sectional area is 3,006

ft^2 as surveyed in 2005. This is a difference (decrease) of about 35%. It is assumed that as the river bed elevation increased, the river water level increased accordingly for the various freshet recurrence intervals. In other words, the flood elevations may be higher than shown in Table 1 and the average velocities may be less than shown. This means that the scour velocity, shear stress, and critical sediment diameter are conservatively high. Calculation results, however, suggest that the river has been aggrading (depositing sediment) more than degrading (scouring), given the input parameters.

Blodgett (1986) provides a less sophisticated relationship of scour depth to median size of bed material in the channel. The relationship is expressed as:

$$d_s = 1.42\ D_{50}^{-0.115},$$

where d_s is the mean depth of scour. Calculations [$1.42(2/12)^{-0.115} = 1.7$ feet] indicate that the local scour during flood flows may be on the order of 2 feet.

Discussion

The coarse, cohesionless nature of the river bed material suggests that the river bed may scour locally based on the river velocity and carrying capacity of the river. The river bed load is assumed to be subject to some transport during flood stages of the river and the distribution of the bed load is assumed to change seasonally in response to river flow. The calculations suggest that the river has been aggrading more than degrading.

Given the calculation results, during normal flow (less than flood flow) the river bed aggrades as material is transported downstream of the steep valleys in the Cascade Mountains. During flood flows, the river bed is scoured in places to a depth of about 2 feet. But as the flood flows recede, sediment is deposited and the elevation of the river bed returns to its pre-flood elevation or higher.

References

ASCE. **Predicting Bed Scour for Toe Protection Design for Bank Stabilization Projects**. American Society of Civil Engineers Continuing Education Seminar, 2005.

Blodgett, J.C, and C.E. McConaughy. **Rock Riprap Design for Protection of Stream Channels Near Highway Structures, Volume 2 – Evaluation of Riprap Design Procedures**. U.S. Geological Survey, Water-Resources Investigations Report 86-4127, Sacramento, CA, 1986.

FEMA. **Flood Insurance Study, King County Washington and Incorporated Areas**. 3 Volumes, Revised: December 6, 2001

Lagasse, P.F., J.D Schall, and V.E. Richardson. **Stream Stability at Highway Structures**. Third Edition, Report FHWA NHI 01-002, Federal Highway Administration, Hydraulic Engineering Circular No. 20, U.S. Department of Transportation, Washington, D.C., 2001.

Stream Channel Equilibrium Slope Calculations
Per Lagasse et (2001)*

Step	Item/Description	Symbol	Units	Calculations				
1	Calculation Identification	-	-	H w/o	H w	L w/o	L w	100-Yr
2	Specific weight of water	g	lbf/ft^3	62.4	62.4	62.4	62.4	62.4
3	Specific weight of sediment	g_s	lbf/ft^3	167	167	167	167	167
4	Mannings roughness coefficient	n	-	0.03	0.03	0.03	0.03	0.03
5	Median sediment diameter	D_{50}	mm	50	50	50	50	50
6	Average channel discharge	Q	ft^3/sec	12,000	12,000	6,000	6,000	54,300
7	Wetted channel cross-sectional area	A	ft^2	1,147	743	325	249	3,009
8	Wetted channel perimeter	P	ft	215	122	200	118	248
9	Average channel width at average channel discharge	W	ft	213	120	197	115	240
10	Existing channel slope	S_{ex}	-	0.00280	0.00280	0.00280	0.00280	0.00280
11	Distance upstream of base level control	L	ft	600	600	600	600	600
12	Hydraulic radius of channel	R	ft	5.3	6.1	1.6	2.1	12.1
13	Average channel velocity	V	ft/sec	10.5	16.2	18.5	24.1	18.0
14	Shields parameter	K_s	-	0.03	0.03	0.03	0.03	0.03
15	Sediment roughness	k_s	ft	0.851	0.851	0.851	0.851	0.851
16	Boundary shear stress	t_o	lbf/ft^2	1.80	4.05	10.65	15.47	3.79
17	Diameter of Sediment at incipient motion	D_c	mm	175.17	393.12	1034.09	1502.47	368.53
18	Channel discharge per unit width	q	ft^2/sec	56.3	100.0	30.5	52.2	226.3
19	Channel slope for stable D_c with no upstream sediment supply	S_{eq}	-	0.01098	0.02130	0.23498	0.25261	0.00965
20	Sediment supply coefficient	a	-	0.000003	0.000003	0.000003	0.000003	0.000003
21	Sediment supply exponent	b	-	3.67276	3.67276	3.67276	3.67276	3.67276
22	Sediment supply exponent	c	-	0.64433	0.64433	0.64433	0.64433	0.64433
23	Sediment transport capacity per unit width	q_s	ft^2/sec	0.04638	0.25004	0.17426	0.55229	0.59211
24	Channel slope for stable D_c with upstream sediment supply	S_{eq}	-	0.00473	0.00935	0.07126	0.08448	0.00456
25	Ultimate degradation at distance L with no sediment supply	Y_s	ft	-4.91	-11.10	-139.31	-149.89	-4.11
26	Ultimate degradation at distance L with sediment supply	Y_s	ft	-1.16	-3.93	-41.08	-49.01	-1.05

* Lagasse, P.F., J.D Schall, and V.E. Richardson. *Stream Stability at Highway Structures* . Third Edition, Report FHWA NHI 01-002, Federal Highway Administration, Hydraulic Engineering Circular No. 20, U.S. Department of Transportation, Washington, D.C., 2001.

1-11	User input calculation identification, specific weight of water, specific weight of sediment, Mannings roughness coefficient, median sediment diameter, average discharge, average wetted channel cross-sectional area, wetted channel perimeter, average channel width, existing channel slope, and distance upstream of base level control.
12	$R = A/P$
13	$V = Q/A$
14	$K_s = 0.047$ for $D_{50} < 2$ mm; $K_s = 0.03$ for $D_{50} > 2$ mm.
15	$k_s = 3.5D_{84} = 3.5D_{50}e^{[0.01157(84)-0.5785]}$
16	$t_o = (gn^2V^2)/(2.208R^{1/3})$ for $D_{50} < 2$ mm; $t_o = (gV^2/g)/[5.75\log(12.27R/k_s)]^2$
17	$D_c = t_o/[K_s(g_s-g)]$
18	$q = Q/W$
19	$S_{eq} = \{K_s(D_c e^{[0.01157(90)-0.5785]})[(g_s-g)/g]\}^{(10/7)}[1.486/qn]^{(6/7)}$
20	$a = 0.025n^{[2.39-0.8\log(D50)]}(D_{50}-0.07)^{-1.4}$
21	$b = 4.93-0.74\log(D_{50})$
22	$c = -0.46+0.65\log(D_{50})$
23	$q_s = aV^b(A/W)^c$
24	$S_{eq} = \{a/q_s\}^{[10/3(c-b)]}q^{[2(2b+3c)/3(c-b)]}(n/1.486)^2$
25-26	$Y_s = L(S_{ex}-S_{eq})$